C-A Unreviewed Safety Issue (USI) Form

Title of USI: Discovery of RHIC SAD ODH Calculation Error

Description of USI (use attachments if necessary): The calculation used to determine the RHIC buildings ODH classifications was found to be in error. The computation of the building oxygen concentration was incorrectly translated into a MathCAD program, resulting in a minimum calculated oxygen concentration that was unconservatively high. The estimated frequency of the design basis helium release used in the SAD calculation was extremely high (i.e., about once per day). The two errors compensated for each other so that the error did not result in an increase in the probability of the event and did not increase the consequences of the event so that the ODH classifications were increased. A new calculation was performed and independently checked for accuracy (see attached memo from R. Karol to E. Lessard, Collider ODH Calculations – Revisited", 4/18/00). The new calculation verified the current RHIC SAD building ODH classifications.

Title and Date of Relevant SAD: RHIC SAD (12/30/99)

Committee Chair or ESHQ Division Head must initial all items. Leave no blanks:

ITEM	APPLIES	DOES NOT APPLY
Decision to not revise the current SAD and/or ASE at this time: The hazard associated with the proposed work or event is covered within an existing SAD and/or ASE. SAD Title and Date: _RHIC SAD 12/30/99_ . This Form and attachments, if necessary, shall be used to document the USI until the next revision of the appropriate SAD.	*Rell*	
Decision to submit a revised SAD and/or ASE to the BNL ESH Committee: N/A $ The hazard associated with the proposed work is not appropriately included in an SAD. (NoT APPLICABLE)	*Rell*	

_____ _4/19/00_
Signature of C-A Committee Chair or C-A ESHQ Division Head   Date

_____ _4-19-00_
Signature of C-A Associate Chair for ESHQ   Date

BROOKHAVEN
NATIONAL LABORATORY

Memo

Date: May 16, 2000

To: W. Glenn

From: R. C. Karol

Subject: Determination of the Probability of a RHIC Tunnel Sextant
               Helium Pressure Boundary Failure

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The probability of RHIC helium system pressure boundary failure has been estimated using conservative engineering judgment [1]. That estimate is further supported by the information in this memorandum. The SBMS Subject Area, Oxygen Deficiency Hazard (ODH) states that the probability of the event shall be found using actual equipment failure rates, if they are known. If they are not known, the values in the Subject Area tables of Fermilab and Nuclear Regulatory Commission (NRC) failure rate data should be used. The approach used for determination of the RHIC helium release probability used actual, updated Fermilab data coupled with actual HFBR data. These two actual sets of data were combined using engineering judgment to produce a conservatively high release frequency. The actual data method satisfies the SBMS requirements and allows for an adequate, logical graded approach for the control of oxygen deficiency hazards at RHIC.

Further supporting data were obtained from Soyers [2] for Fermilab cryogenic failure rates based on actual Fermilab data. A discussion of this information follows:

For a cryogenic compressor rupture, the current model was based on about 33,300 hours of rupture-free data accumulated through the late 1980s. By conservatively assuming one rupture at the end of this interval, the rupture rate was found to be 3E-05/hr. New data recently compiled by Soyers [2] shows that 25 compressors have each run for 125,000 hours (3.125E06 total hours) without a rupture event. Again, assuming that a rupture occurs following this interval, results in a rupture frequency estimate of 3E-07/hr. Further refinement of this estimate using Bayes Equation [3] (see Appendix 1), shows the actual rupture frequency to be <1E-08/hr.

A cryogenic fluid line rupture is currently estimated to be 3E-06/hr. New data [2], which consists of 63E06 rupture-free hours, shows this estimate to be reduced to 2E-08/hr. Using the Appendix 1 method, this value is shown to be <1E-08/hr, which is more in line with the NRC estimate of 1E-10 to 1E-09 per hour, depending upon the pipe diameter. The NRC data includes many more hours of operation than the limited data from Fermilab and is closer to the actual failure rate value.

A cryogenic magnet rupture is currently estimated to occur at a frequency of 1E-06/hr. Soyers [2] now estimates this value to be reduced to 2E-08/hr using actual data. In updating this value

he conservatively included two precursor events that did not result in actual pressure boundary failures. Taking a more realistic approach (i.e., no ruptures to date) results in a rupture frequency estimate of 1E-08/hr, based on 89E06 hours of rupture-free operation of unpowered magnets. Using the refinement method of Appendix 1 reduces this rupture frequency to <1E-08/hr.

The conclusion of this discussion is that the Fermilab component rupture rate data is logically derived but is conservatively high. Using it as the sole source of data would lead to higher rupture rates than actual and would lead to excessive, costly hazard controls for ODH. The conservative approach is the assumption of one failure at the end of the accumulated failure-free hours.

Based on this argument, it is recommended that the method used in Reference 1 to determine the probability of a Collider design basis helium release, be accepted by the ASSRC with concurrence from the BNL ESH Committee. Alternate methods are normally allowed, with justification and BNL approval, if they have strong bases. It is noted that alternate methods, supported by strong arguments, are accepted by the Nuclear Regulatory Commission and the DOE when not following NRC Regulatory Guides or DOE Orders.

References:

1. Karol, R., "Collider Building ODH Calculations – Revisited", April, 18, 2000
2. Soyers, B., "Appendix: Rationale for Table 1 – Fermilab Equipment Failure Rate Estimates," January 26, 2000.
3. McCormick, N.J., "Reliability and Risk Analysis – Methods and Nuclear Power Applications," Academic Press, 1981. Section 2-2.

Appendix 1

Use Bayes Equation [3] to determine a best estimate of the value of component failure.

Use the record of past failure-free events (an event is one hour of operation without a pressure boundary failure) to assess the probability of failure in any one-hour interval.

The example used here will be for a compressor system rupture. Current data from Fermi by Soyers [1] shows that there was no rupture for 3.125×10^6 hours. Let B stand for the statement "we have 3.125×10^6 hours without a rupture", and let A, represent the hypothesis that the probability of release per shipment is 10^{-6} each hour (or event). Other hypotheses A_n (n = 2 to 6) are shown in the following table:

n	1	2	3	4	5	6
A_n	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}
$P(B|A_n)$	0.044	0.732	0.969	0.997	0.9997	0.99997
Uniform Prior:						
$P(A_n)$	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
$P(A_n|B)$	0.009	0.154	0.204	0.210	0.211	0.211

The values in the above table were found as follows:

$$P(B|A_1) = (1 - 10^{-6})^{3,125,000} = 0.044$$
….
….
$$P(B|A_6) = (1 - 10^{-11})^{3,125,000} = 0.99997$$

A uniform prior distribution is assumed since knowledge of the actual value of A_n is not known. Thus the probability for each of the six hypotheses is 1/6 or 0.1667.

The value of $P(A_n|B)$, which means the probability that the hourly failure rate is A_n, given 3.125×10^6 failure-free hours, is found by [2]:

$$P(Am/B) = \frac{P(Am)P(B/Am)}{\sum_{m=1}^{N} P(Am)P(B/Am)}$$

It is concluded with the experience of 3.125×10^6 hours of rupture free operation that the probability of rupture is less than 10^{-8}/hr.

BROOKHAVEN
NATIONAL LABORATORY

Memo

Date: May 18, 2000

To: W. Glenn

From: R. C. Karol

Subject: Calculated Oxygen Concentration vs. RHIC Helium Gas Release Test Data

As requested, a comparison of the RHIC helium gas release test oxygen concentration data [1] with a Fermi ODH homogenous mixing model calculation has been made. The RHIC test spill rate is shown in Figure 1. This release occurred at 50K. A fit of the curve in Figure 1 is:

$R = 4517.1 * \exp(-(t - .2676263)^2/(2 * (3.5759)^2))$ SCFM   for t = 0 to 6 minutes

$R = 7.334378 * \exp((\ln(t) – 4.82774)^2/1.79341)$ SCFM   for $6 < t < 11$ minutes

R= 200 SCFM   for $t > 11$ minutes

A QuickBasic code was written to determine the tunnel oxygen concentration as a function of time. The minimum computed oxygen concentration is 19.9 %, about 410 seconds following helium release initiation. This compares well with a simple calculation in which the total helium release volume (~21,000 SCF) displaces the air in the tunnel sextant 5 volume of 390,000 ft^3. This would cause the average oxygen concentration to fall to 19.88%.

Actual data taken during the spill test were reviewed. The lowest recorded oxygen concentration was 9%, twenty feet from the spill. Recorded concentrations as a function of distance from the spill were as follows:

Location (ft from spill)	Max / Min O2 (%)
At spill	10.8 / 14.8
20	9 / 15
50	13 /16.9
100	12.9 / 15.7
300	18.1

Thus, the homogeneous mixing model does not predict the instantaneous measured values well. The homogeneous model, which is prescribed at Fermi and in the BNL SBMS does, however, provide a logical way to apply a graded approach in the treatment of ODH hazard controls. The assumption of uniform instantaneous mixing in a volume that has inflow and outflow that varies with time is common in internal radiation dose and environmental dose assessments and in reactor accident analyses. Although it may not accurately reflect the instantaneous concentrations in time and space, it is a common, prescribed approach that allows for the determination of a hazard level that is reasonable and practical over a broad range of spill events. This is what it has accomplished for the ODH controls for RHIC buildings. The model determines the following for each building that has the potential for a large helium release:

1. The number of operable exhaust fans.
2. The level of training for unescorted personnel.
3. The medical protocols for personnel entering the building.
4. The personnel protective equipment necessary for the higher hazard buildings.
5. The review of the operability of escape paths.

It is noted that although the actual oxygen concentrations following the spill test were significantly lower than the model predicts, the minimum oxygen concentrations about 300 feet away from the release are close to the model prediction. This distance compares to the total distance of a Tunnel Sextant of about 2100 feet. The tunnel is not a confined or restricted space, and the training emphasizes that evacuation following an ODH alarm should be immediate and the exit path is to be away from the location of noise or escaping fog. Thus, the actual exposure of a person through a gradient of oxygen concentrations is better reflected by the homogeneous model since localized low oxygen concentrations would have no effect on the successful escape of personnel.

BROOKHAVEN
NATIONAL LABORATORY

Memo

Date: May 22, 2000 (Revised May 25, 2000)

To: W. Glenn

From: R. C. Karol

Subject: Discussion of Use of BNL Standards Based Management System (SBMS) Oxygen Deficiency Hazard (ODH) Failure Rate Estimates vs. Actual Failure Rate Data (Revised)

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This memorandum discusses the BNL SBMS ODH Subject Area equipment failure rates. These estimates are based on cryogenic equipment operating data from Fermilab and plant operating data from the Nuclear Regulatory Commission (NRC).

The estimates for failure rates at Fermilab, for the most part, are based upon accumulated hours without failure. The conservative assumption is that a failure occurs at the end of the accumulated hours. For example, if 1000 hours were accumulated, the failure rate would be (1/1000) or 1×10^{-3}/hr. As more failure-free hours are accumulated, the estimated failure rate decreases and approaches the true rate. A recent update of the Fermilab data by Soyers [1] has shown that the estimated failure rates have dropped by a factor of over 100 for both cryogenic fluid lines and cryogenic magnets [2]. This decrease is expected to continue as more operating time accumulates.

Use of the current SBMS failure rate estimates yielded unacceptably high failure rates for previous ODH calculations [3]. The computed helium rupture rates, using the SBMS estimated equipment failure rates, resulted in values that are unrealistic. For example, considering a RHIC Sextant cryogenic piping and magnets, the calculated frequency for the bounding cold helium release, using the SBMS values in the old calculation would be:

$(3 \times 10^{-6}$/hr per pipe section) $(888$ pipe sections$) + (1 \times 10^{-6}$/hr per magnet) $(180$ magnets$) = 2.844 \times 10^{-3}$/hr

This yields an unrealistic rupture frequency of once every 2-weeks. If the 6-Sextants and the Service/Support Building frequencies are summed, the expectation is that a major rupture would occur daily. This result is obviously not realistic. Additional equipment failures were assumed in the original calculation. The bases for these equipment failures were not documented and personnel involved in the analyses do not recollect their bases.

A recent calculation [4] has used actual data, coupled with engineering judgment, to determine the frequency of major cold helium system ruptures. The new frequency value estimates (using engineering judgment) ranged from once every 11 to once every 38 years. These estimates, which are still conservative, compare to the HFBR primary pipe rupture frequency of once every 10,000 years. Using the new data from Soyers [1,2], yields a conservative but more reasonable frequency:

$$(10^{-8}/\text{hr per pipe section}) (888 \text{ pipe sections}) + (10^{-8}/\text{hr per magnet}) (180 \text{ magnets}) = 1.068 \times 10^{-5}/\text{hr}$$

This is a frequency of once every 10.7 years, which supports the value used in the revised ODH calculation of Reference 4. A review of the system shows that only cryogenic piping or magnet failures can lead to helium pressure boundary failures. Consideration of fan, O_2 sensors, electrical power failures, concurrent with the pressure boundary failure, would only reduce the frequency of occurrence, so these failures have been conservatively ignored.

It is concluded that use of the current BNL SBMS failure rate estimates are not appropriate for determining the ODH class of the RHIC Buildings. Use of actual updated Fermilab data allows for a better determination of the RHIC Building and Tunnel Sextant ODH classes.

References:

1. Soyers, B., "Appendix: Rationale for Table 1 – Fermilab Equipment Failure Rate Estimates," January 26, 2000.
2. Karol, R., "Determination of the Probability of a RHIC Tunnel Sextant Helium Pressure Boundary Failure", May 16, 2000.
3. Iarocci, M., "Calculation of Oxygen Deficiency Hazard Classes for RHIC", August 1994.
4. Karol, R., "Collider Building ODH Calculations – Revisited", April 18, 2000.

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managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: April 18, 2000 **(Revised 5/26/00)**

To: E. Lessard

From: R. C. Karol

Subject: Collider Building ODH Calculations - Revisited

Purpose

To compute the appropriate ODH class for the Collider Compressor Building, Refrigerator Building, Tunnel Sextants and the six Support Buildings, which contain the valve boxes. Oxygen deficiency can be caused by a leak of cold helium fluid present in these buildings. As suggested by the ASSRC Chairman, this revised memorandum incorporates information contained in References 1 through 4. It also uses a better estimate for the helium spill rate into a Tunnel Sextant. This new spill rate information was obtained directly from Reference 5 instead of Reference 6.

Summary and Conclusions

The goal of this calculation is to determine the Oxygen Deficiency Hazard (ODH) risk for the Collider Buildings by estimating the fatality rate for a major helium release. A spectrum of events may cause an oxygen deficiency. A major helium system failure has been chosen to bound the consequences of all credible failures [6]. Table 1 summarizes the bounding events considered for each Collider Building. The table shows the maximum initial helium spill rate for each building, and the probability of the design-basis helium-system pressure-boundary failure. The initial spill rates were taken from the RHIC SAD [7] and Reference 5. The probabilities for pressure boundary failure were estimated using the guidance from the Fermi Model (updated – see Reference 2). The results of the calculation for each building are shown in Tables 1 and 2. In all cases, the current ODH classes for the Collider Buildings have been confirmed. For some cases the revised calculation shows that no oxygen deficiency hazard exists. However, a minimum ODH Class of 0 has been chosen due to the uncertainty in the model and to uniformly apply ODH controls at the Collider.

In order to assure that the exhaust fan configurations assumed in the ODH calculations are operable, testing ODH exhaust system fans prior to introducing cold helium gas (<50K) should be conducted to verify the following:

1. At least one fan in each Support Building is operable.
2. At least three fans in the Compressor Building are operable.
3. At least one fan in the Refrigerator Building is operable.
4. At least three fans in each Tunnel Sextant are operable (minimum total capacity of 60,000 CFM per sextant).

Applicable Criteria

The method in the BNL ODH Subject Area, supplemented with updated Fermilab equipment failure rate data [2] was used to determine the ODH class for each Collider Building listed in Table 1. This method is the same used in the original calculation [6].

Assumptions

1. Building volumes, exhaust fan capacities and peak helium spill rates were taken from the RHIC SAD, Table 4-A-2, Oxygen Deficiency Hazard of Collider Buildings During Normal Operation. The maximum spill rate for a Tunnel Sextant was taken directly from Reference 5 rather than Table 4-A-2.

2. The time variation of the helium spill rate (in CFM, referenced to 70F) into each building (except Compressor and Refrigerator Buildings) varied as specified in previous ODH calculations [5,6]. This revised memorandum has used a better estimate of the time variation for the helium spill rate in a Tunnel Sextant. The calculated data from Reference 5 was used directly for the Tunnel transient. Examination of the helium spill transient used in Reference 6 (which also used Reference 5 data) was determined to result in overestimation of the ODH in the Tunnel Sextants.

3. The helium spill rates for the Compressor (1005H) and Refrigerator (1005R) Buildings were assumed to be constant, which overestimates the ODH.

4. The building exhaust fans start when the building oxygen concentration is reduced to 18%. Once started, the fans will run for at least 3 minutes, even if the oxygen concentration is restored to >18%. This logic, although included in the calculation, has no impact on the minimum computed oxygen concentration or the building ODH class.

5. Outside air drawn into the building has a 21% oxygen concentration.

6. The building pressure remains constant and very near atmospheric pressure through the use of louvers or natural leakage.

7. The oxygen concentration in the building is found by assuming instantaneous mixing of the air and helium in the building volume. Justification of the validity of this assumption is discussed in Reference 3.

8. Estimates of the probability per hour of a major helium pressure boundary failure for each building is shown in Table 1. These values are based upon actual data from Fermilab and the Nuclear Regulatory Commission. The bases behind these values are summarized in Appendix A. The use of these failure rates overestimates the frequency of the accident because the Fermilab data is based upon failure-free equipment operations. Reference 2 discusses the derivation of these values. The probabilities for the various Collider Buildings vary because of the variation in the inventory of equipment in the

different buildings. The frequency of the bounding helium accident varies from once every 4 years to once every 27 years, depending upon the location of the failure. These values are judged to be overestimates of the failure rate for a major helium release at RHIC. For comparison, a recent High Flux Beam Reactor probabilistic risk assessment used a pipe failure rate of approximately once every 10,000 years [8]. The amount of piping at the HFBR exceeds that located in the Collider Support Buildings, and is on the same order of pipe sections present in the Compressor and Refrigerator Buildings and the Tunnel Sextants.

Detailed Calculation and Analyses

The Fermi Model is a prescribed method to determine the necessary level of hazard control for a building having the potential for oxygen deficiency. The fatality rate in the model is the product of two numbers. One quantity is the probability per hour of an event causing an oxygen deficiency. The other quantity is found by estimating the minimum oxygen concentration during the transient, assuming instantaneous mixing of the air and helium in the building volume, and is represented by a factor between 0 and 1 (see Figure 1). The computed fatality rate is then used to define the ODH class necessary to protect personnel.

The Oxygen Deficiency Hazard fatality rate is defined as:

$$\Phi = PF$$

where Φ = the ODH fatality rate per hour
P = the expected rate of the event per hour, i.e. initiator frequency
F = the fatality factor for the event

The value of P, the initiator frequency, was determined by using actual equipment failure rate data recently updated by Fermilab [2] and by the Nuclear Regulatory Commission [9]. The failure-free equipment operational data from Collider operations has been conservatively excluded when estimating the initiator frequency for this accident.

Figure 1. Graph of the Fatality Factor (logarithmic scale) versus the Computed Oxygen Partial Pressure.
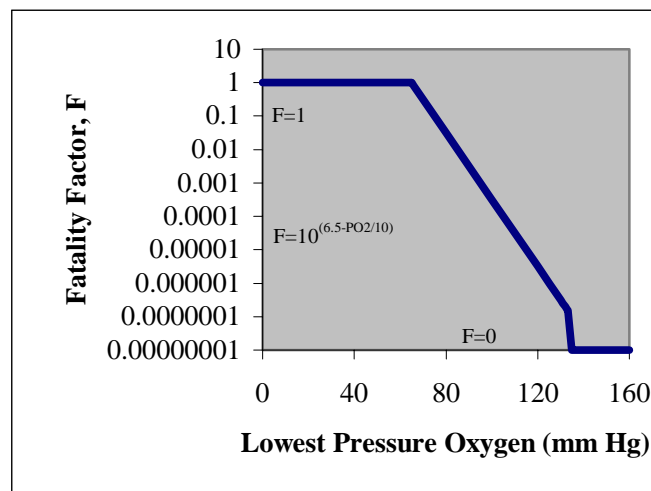
The value of the fatality factor, F, is the probability that a fatality will result if the design basis bounding helium release occurs. Figure 1 from Reference 9 defines the relationship between the value of F and the computed oxygen partial pressure. The partial pressure is found by multiplying the mole fraction of oxygen in the building atmosphere by 760 mmHg. If the oxygen concentration is greater than 18% (~137 mmHg), then the value of F is defined to be zero. That is, all exposures above 18% are defined to be safe and do not contribute to fatality. If the oxygen concentration is 18%, then the value of F is defined to be 10^{-7}. At decreasing concentrations the value of F increases until, at some point, the probability of fatality becomes unity. That point is defined to be 8.8% (~67 mmHg) oxygen in the Fermi model, the concentration at which one minute of consciousness is expected.

The value of Φ, the fatality rate, is then used to determine the ODH class of the building as follows [6,7,8]:

ODH Class	Fatality Rate (per hour)
NA	$<10^{-9}$
0	$\geq 10^{-9}$ but $<10^{-7}$
1	$\geq 10^{-7}$ but $<10^{-5}$
2	$\geq 10^{-5}$ but $<10^{-3}$
3	$\geq 10^{-3}$ but $<10^{-1}$
4	$\geq 10^{-1}$

The oxygen concentration in the building during a release of helium gas is approximated by solving the following differential equations [9]:

(a) If the exhaust fan is on and the spill rate of helium (R) is less than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = 0.21 \, (Q - R) - QC$$

Where

V = building volume (ft^3)
C = oxygen concentration (mole fraction)
t = time (minutes)
Q = exhaust fan(s) flow rate (CFM)
R = helium spill rate into building (CFM)

(b) If the exhaust fan is off or if the helium spill rate (R) is greater than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = - RC$$

The code used for this calculation is attached. A time step of one second was used to obtain the oxygen concentration values.

Spill rates as a function of time were available for the Tunnel Sextants [5] and for the Support Buildings [6]. The revised calculation used a better estimate for the Tunnel Sextant helium spill

rate as a function of time by using calculated data directly from Appendix B of Reference 5 instead of the very conservative values from Reference 6. Table 3 shows a comparison of the fitted equations used in the attached code with the referenced helium release rates. It is noted that the fitted equation accurately represents the transient values from Reference 5. The computed Tunnel Sextant spill rate values were multiplied by a factor of 1.1 to account for uncertainties.

No transient values were available for the Compressor or Refrigerator Buildings, so it was conservatively assumed that these spill rates remained at their peak values. As shown in Table 2, the steady state oxygen concentration for 1005H with a constant spill rate of 8000 SCFM of helium gas, is 18.8% (minimum). Thus, an ODH category of 0 is conservative but appropriate. For 1005R, the assumption of a constant spill rate of 27,000 SCFM will result in an ODH 1 hazard class after about 8 minutes with all fans on or 5 minutes with one failed fan. This is adequate time for an individual to safely exit the building. The probability of having a fan fail $(3x10^{-4}$ per demand) concurrently with helium pressure boundary failure $(3x10^{-5}$ per hour or about once every 4 years) is low enough so that the worst ODH class that needs to be considered for the Refrigerator Building is ODH 1. This conclusion is based upon the conservative frequency used for the pressure boundary failure and the conservative assumption of constant helium release rate.

For the Tunnel Sextants, the worst case would be 1003 or 1011 due to their relatively small volume of 300,000 ft^3 compared to the other Tunnel Sextants. For this case the minimum oxygen concentration was found to be 13.9% with 3 fans running, and 13.6% with two fans running. An ODH 1 class is appropriate if the facility is run at 4K when it is known that less than 3 sextant fans are operable. The reason for this conclusion is that at least 3 operable sextant fans are needed to justify the assumption of instantaneous mixing of the helium and air. The probability of having one of the fans fail ($3 x 10^{-4}$ per demand) concurrently with the bounding helium leak $(1.2x10^{-5}$ per hour) is low enough to keep the tunnel ODH consistent with the current RHIC SAD ODH 0 class.

For all Support Buildings, even with one of the two fans known to be inoperable prior to the accident, the ODH class remains ODH 0.

Dr. Lap Cheng of the Reactor Division has checked this calculation.

References

1. Karol, R., "Collider Building ODH Calculations – Revisited", April 18, 2000.
2. Karol, R., "Determination of the Probability of a RHIC Tunnel Sextant Helium Pressure Boundary Failure", May 16, 2000.
3. Karol, R., "Calculated Oxygen Concentration vs. RHIC Helium Gas Release Test Data", May 18, 2000.
4. Karol, R., "Discussion of Use of BNL Standards Based Management System (SBMS) Oxygen Deficiency Hazard (ODH) Failure Rate Estimates vs. Actual Failure Rate Data (Revised)", May 22, 2000.
5. Wu, K.C., "Estimation of Helium Discharge Rates for RHIC ODH Calculations", September 1995. (AD/RHIC/RD-79).
6. Iarocci, M., "Calculation of Oxygen Deficiency Hazard Classes for RHIC", August 1994.
7. RHIC Safety Assessment Document, Table 4-A-2, "Oxygen Deficiency Hazards of RHIC Buildings During Normal Operations".

8. Azarm, A., et. Al., Level 1 Internal Events PRA for the High Flux Beam Reactor, Volume 1: Summary and Results (Rev. 1)", July 1990.
9. BNL Standards Based Management System Subject Area, "Oxygen Deficiency Hazards".

Table 1

ODH Classification for Collider Buildings

Building No.	Name	Bldg. Vol (ft^3)	Total Fan CFM (# Fans)	Peak He CFM	Frequency[1] (per hr)	ODH Class/Fatality Rate (Φ) Case A	Case B
1005H	Compressor Building	250,000	100,000 (4 fans)	8,000[note 2]	3x10^{-5}	NA / note 6	NA / note 6
1005R	Refrigerator Building	240,000	50,000 (2 fans)	27,000[note 2]	3x10^{-5}	1 / note 7	1 / note 7
1001	Collider Tunnel - 1:00	310,000	60,000 (3 fans)	157,800[note 3]	1.2x10^{-5}	NA / note 8	0 / note 8
1003	Collider Tunnel - 3:00	300,000	60,000 (3 fans)	157,800[note 3]	1.2x10^{-5}	NA / 1x10^{-10}	0 / 1.9x10^{-9}
1005	Collider Tunnel - 5:00	390,000	60,000 (3 fans)	157,800[note 3]	1.2x10^{-5}	NA / note 8	0 / note 8
1007	Collider Tunnel - 7:00	400,000	60,000 (3 fans)	157,800[note 3]	1.2x10^{-5}	NA / note 8	0 / note 8
1009	Collider Tunnel - 9:00	320,000	60,000 (3 fans)	157,800[note 3]	1.2x10^{-5}	NA / note 8	0 / note 8
1011	Collider Tunnel - 11:00	300,000	60,000 (3 fans)	157,800[note 3]	1.2x10^{-5}	NA / 1x10^{-10}	0 / 1.9x10^{-9}
1002B	2:00 Support Building	70,000	32,000 (2 fans)	17,000	3x10^{-6}	NA / 1x10^{-10}	0 / 1.1x10^{-8}
1004B	4:00 Support Building	113,000	44,000 (2 fans)	17,000	3x10^{-6}	NA / 3x10^{-12}	0 / 5.2x10^{-11}
1006B	6:00 Support Building	85,000	32,000 (2 fans)	17,000	3x10^{-6}	NA / 4.1x10^{-11}	0 / 2x10^{-9}
1008B	8:00 Support Building	75,000	32,000 (2 fans)	17,000	3x10^{-6}	NA / 7.4x10^{-11}	0 / 5.9x10^{-9}
1010A	10:00 Support Building	110,000	22,000 (2 fans)	17,000	3x10^{-6}	NA / 6.1x10^{-11}	0 / 8.6x10^{-10}
1012A	12:00 Support Building	110,000	22,000 (2 fans)	17,000	3x10^{-6}	NA / 6.1x10^{-11}	0 / 8.6x10^{-10}

Notes:

(1) Frequency is given as the probability per hour that the bounding helium system failure occurs within the building.

(2) Conservatively assumed to be constant at these helium spill values for 1005H and 1005R. The minimum ODH Class for the Compressor Building is conservatively set at ODH 0 due to the inventory of the helium present in the building and in order to simplify ODH controls.

(3) Peak spill rate obtained from Reference 5, Appendix B (see Table 3).

(4) Case A is all building fans operational. The minimum ODH Class for the Tunnel Sextants and the Support Buildings is conservatively set at ODH 0 due to the inventory of helium present in the buildings and in order to simplify ODH controls.

(5) Case B considers one fan failed. The ODH Class for all Support Buildings is based on the worst case to simplify ODH controls.

(6) For the Compressor Building, the oxygen concentration will only fall to a minimum of 18.8%. See Table 2. The minimum ODH Class for the Compressor Building is conservatively set at ODH 0 due to the inventory of the helium present in the building and in order to simplify ODH controls.

(7) For the Refrigerator Building the time to ODH 1 was determined ($\Phi = 10^{-7}$). See Table 2 and text pages 4 and 5.

(8) Tunnel Sextants 1003 and 1011 bound the conditions for all sextants because they have the smallest volumes.

Table 2

Minimum Computed O$_2$ Concentrations
(normal atmosphere has 21% oxygen)

Building	All Fans On	One Fan Failed [1]
1005H	19.3% (steady state)	18.8% (steady state)
1005R	11.8% after 8 minutes[2]	11.8% after 5 minutes[2]
1001	Note 3	Note 3
1003	13.9% @ 112 sec.	13.6% @ 129 sec.
1005	Note 3	Note 3
1007	Note 3	Note 3
1009	Note 3	Note 3
1011	13.9% @ 112 sec.	13.6% @ 129 sec.
1002B	14.4% @ 165 sec.	11.8% @ 225 sec.
1004B	16.4% @ 175 sec.	14.8% @ 240 sec.
1006B	15% @ 180 sec.	12.7% @ 245 sec.
1008B	14.6% @ 170 sec.	12.1% @ 235 sec.
1010A	14.7% @ 235 sec.	13.2% @ 300 sec.
1012A	14.7% @ 235 sec.	13.2% @ 300 sec.

Notes:
(1) One of the fans fails to start on demand during the helium spill transient
(2) An oxygen concentration of 11.8%, coupled with the conservatively estimated probability of the accident results in a value of the fatality factor (Φ) that corresponds to the threshold of an ODH class 1 ($\Phi=10^{-7}$) for the all-fans-on condition. This same oxygen concentration was used for the one-fan-failed condition.
(3) These Tunnel Sextants would experience a milder transient (i.e. minimum oxygen concentrations higher than sextants 1003 and 1011). This is because of their larger volumes while having the same exhaust fan capacities.

Table 3

Curve Fit of K.C. Wu Tunnel Sextant Helium Leak Rate (Ref. 5)

$$Q = \frac{mRT}{P} = \frac{(X\text{ g/s})(\text{lbm/453.6g})(386.25\text{ ft-lbf/lbm-R})(530\text{R})(60\text{sec/min})}{14.7 \times 144\text{ lbf/ft}^2}$$

T (sec)	M_{He} (g/sec)	CFM (at 70F)	Curve Fit (CFM)
0	12329	157800	157800
9	12329	157800	157800
16	10624	136000	137825
23	9304	119100	119090
29	8240	105475	105074
35	7351	94100	92707
40	6590	84350	83520
45	5927	75910	75245
50	5346	68480	67788
55	4828	61825	61070
64	4090	52350	50612
73	3327	42590	41945
82	2704	34630	34762
91	2170	27780	28809
102	1730	22144	22900
112	1367	17540	18586
125	1075	13760	14169
138	845	10820	10665
153	665	8510	9060
170	526	6735	7532
189	418	5350	6126
211	334	4275	4823
235	268	3430	3716
263	217	2780	2740

Notes:

1) Helium mass flow rates (g/sec) at listed times were obtained from Reference 5, Appendix B.
2) Curve fit equations for R(t):

0 sec $\leq$ t $\leq$ 9 sec	R(t) = 157800 CFM
9 sec $<$ t $\leq$ 138 sec	R(t) = 192465 $e^{-0.0208706t}$ CFM
138 sec $<$ t $\leq$ 263 sec	R(t) = 47800 $e^{-0.01087t}$ CFM
t $>$ 263 sec	R(t) = 2780 CFM

```
'code to compute the ODH class of a building vs time
'designed with fans exhausting building when on
'CODE: ODH       By: Ray Karol    3/22/00
'revised 5/8/00 to correct initial value of trun to 0
'revised 5/26/00 to update tunnel spill rate vs time and to save phimax

CLS : t = 0: coxy = .21: cmin = .22: flag = 0: phimax = 1E-20
a = 1.17712E-11: b = -2.11362E-08: c = 1.37861E-05
d = -4.06769E-03: e = .636119: f = -102.303: g = 17124.4
INPUT "time step (sec)"; dt
INPUT "Building volume (ft3)"; v
INPUT "Fan capacity Q (SCFM)"; q
INPUT "Fans start when oxygen falls to (%)"; trip: trip = trip / 100
INPUT "Helium release probability (per hr)"; prel
INPUT "Tunnel (1) or service building (2) leak"; bbb
INPUT "Building number"; build$

'print out initial conditions:
PRINT "time step ="; dt; "sec"
PRINT "Building volume ="; v; "ft3    Building "; build$
PRINT "Fan capacity ="; q; "SCFM"; "    Fan starts at"; trip * 100; "% O2"
PRINT "Probability of He release"; prel; "per hour"
PRINT " t (sec)   R(SCFM)   O2 (fract)  PO2 (mm Hg)  Fat factor   phi    ODH "
PRINT " _____   _____  _____  _____  _____   ___    ___"

'find leak rate of helium during time step
10 IF bbb < 1.9 THEN GOSUB leak ELSE GOSUB leak1

'oxygen concentration during time step (%):
IF flag < .9 THEN GOSUB oxyleak: 'fan off condition
IF flag > .9 THEN GOSUB oxyleak1: 'fan on condition

'get minimum oxygen concentration and corresponding time:
IF cmin > coxy THEN cmin = coxy: tmin = t: fermi = odh

'oxygen partial pressure during time step (mm Hg):
poxy = coxy * 760

'fatality factor using Fermi ODH guidance:
IF poxy > 137 THEN fatfac = 0
IF poxy <= 67 THEN fatfac = 1
IF poxy <= 137 AND poxy > 67 THEN fatfac = 10 ^ (6.5 - (poxy / 10))

'ODH fatality factor from Fermi ODH guidance:
phi = prel * fatfac: IF phi > phimax THEN phimax = phi
IF phi < 1E-09 THEN odh = -1
IF phi >= 1E-09 AND phi < .0000001 THEN odh = 0
IF phi >= .0000001 AND phi < .00001 THEN odh = 1
IF phi >= .00001 AND phi < .001 THEN odh = 2
IF phi >= .001 AND phi < .1 THEN odh = 3
IF phi >= .1 THEN odh = 4

t = t + dt
IF ABS(t / 10 - CINT(t / 10)) < .009 THEN
        PRINT USING "##.##^^^^  "; t; r; coxy; poxy; fatfac; phi; odh
END IF
```

```
IF t > 1200 THEN
        PRINT USING "##.##^^^^  "; tmin; cmin; phimax; fermi
'        print CHR$(12)
        END
END IF
GOTO 10
'subroutines for leak rate:
'first for the service buildings:
leak1:
IF t < 60 THEN r = 17000
IF t >= 60 AND t < 540 THEN
        tt = t - 60: 'convert to correct time for the fit equation
        first = a * tt ^ 6 + b * tt ^ 5 + c * tt ^ 4
        second = d * tt ^ 3 + e * tt ^ 2 + f * tt + g
        r = first + second
        IF r > 17000 THEN r = 17000
        IF r < 2000 THEN r = 2000
END IF
IF t >= 540 THEN r = 2000
RETURN
'then for the tunnel:
leak:
IF t <= 9 THEN r = 157800: 'initial spill rate
IF t > 9 AND t <= 138 THEN
        r = 192465 * EXP(-.0208706 * t)
ELSE
        r = 47800 * EXP(-.01087 * t)
END IF
IF r > 157800 THEN r = 157800: 'maximum flow rate
IF r < 2780 THEN r = 2780: 'minimum flow rate
r = r * 1.1: 'conservative multiplier
RETURN


'subroutine to find oxygen concentration if fan off:
oxyleak:
IF r > 0 THEN
        dcoxy = -r * coxy / v * dt / 60
        coxy = coxy + dcoxy
END IF
'see if fan starts:
IF coxy <= trip AND flag < .9 THEN flag = 1: trun = 0
RETURN


'subroutine to find oxygen concentration if fan on:
oxyleak1:
IF r > q THEN
        dcoxy = -r * coxy / v * dt / 60
        coxy = coxy + dcoxy
ELSE
        dcoxy = (.21 * (q - r) - q * coxy) * dt / 60 / v
        coxy = coxy + dcoxy: flag = 1
END IF
'see if fan timed out after O2 returns to 18%
IF coxy < .18 THEN flag = 1: trun = trun + dt
IF coxy >= .18 THEN
        IF trun < 180 THEN trun = trun + dt
        IF trun >= 180 THEN flag = 0: trun = 0
END IF
RETURN
```

Appendix A
Collider Building Helium Pressure Boundary Failure Probabilities

1. **Tunnel Sextant**

   The major items of equipment that could fail and release helium are magnets and magnet interconnections (piping sections). There are no direct connections (i.e., valves or reliefs) from the cold helium volume to the tunnel. There are about ten Joule-Thompson valves per sextant, but these are in a pipe system and only act as a pressure boundary. Pipe pressure boundary failures are estimated to be 10^{-8}/hr per valve by the NRC [9]. One sextant has on the average 180 magnets (Dipoles, CQS, DX, DU and Triplets) and no more than 1000 interconnections and valves. Using the updated Fermilab data for magnets and pipe sections from Reference 2 yields:

   $$(10^{-8}/\text{hr per pipe section/valve}) (\sim 1000 \text{ pipe sections and valves}) + (10^{-8}/\text{hr per magnet}) (\sim 180 \text{ magnets})$$
   $$= 1.2 \times 10^{-5}/\text{hr}$$

2. **Support Buildings**

   The major items in these buildings are piping sections and valves. All helium system reliefs are routed outside the building. Visual inspection of the buildings shows that there are much less than 300 pipe sections/valves per building with each component failure rate at 10^{-8}/hr. The value used in the previous version [1] of the calculation (3×10^{-6} /hr) will be retained for conservatism.

3. **Compressor and Refrigerator Buildings**

   Visual inspection of these buildings resulted in the conclusion that about 1000 pipe sections, valves and equipment are present per building. To be conservative a value of 3000 was used. Using the updated Fermilab equipment failure rates [2] for piping and compressors and NRC data for valve ruptures yields:

   $$(10^{-8}/\text{hr}) (\sim 3000 \text{ pipe sections and equipment}) = 3 \times 10^{-5}/\text{hr}$$

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Memo

Date: June 6, 2000

To: W. Glenn

From: R. Karol

Subject: Response to Additional ODH Issues Raised at ASSRC Subcommittee Meeting

---

This memorandum answers additional ASSRC questions regarding multiple events occurring at the same time that were asked at the 6/6/00 subcommittee meeting on ODH. In this memorandum, event rates much much less than 1 are treated as probabilities in one hour.

Issue 1:
What is the ODH Class for a RHIC Building if 1) a backup diesel generator, which supplies power to ODH fans if offsite power is lost, is known to be out of service, 2) offsite power is lost, and 3) a helium pressure boundary failure occurs?

For this case, the event rate of the diesel failure is 1 per hour. The joint probability of a helium pressure-boundary failure concurrent with loss of offsite power in the same hour must be determined. The helium pressure boundary failure event rate is highest for the Refrigerator or Compressor Buildings and is 3×10^{-5} per hour [1]. The event rate of loss of offsite power is 1×10^{-4} per hour, which is obtained from the BNL SBMS ODH subject area, Equipment Failure Rate Estimates. For comparison, a recent study of the High Flux Beam Reactor [2] determined that the frequency of offsite power loss, lasting between 3 seconds to 2 hours is 4.4×10^{-5} per hour. Using the higher SBMS frequency for offsite power loss, results in the probability of both pressure boundary failure and loss of offsite power in the same hour of 3×10^{-9}.

Assuming no forced ventilation of the building because the power to the fans is lost and, ignoring any natural ventilation effects, the building will eventually reach 100% helium or 0% oxygen concentration following leak initiation. Since this is < 8.8% oxygen, the Fatality Factor (F) is equal to 1. The Fatality Rate (Φ) is found to be:

$$\Phi = PF = (3 \times 10^{-9} \text{ in one hour})(1) = 3 \times 10^{-9} \text{ per hour}$$

Since the Fatality Rate is $<10^{-7}$ per hour, the ODH Class is Class 0.

Issue 2:
What is the ODH Class for a RHIC Building if 1) a loss of offsite power occurs, 2) the diesels fail, and 3) a helium pressure boundary failure occurs?

As described above, the Fatality Factor (F) will be 1 because all fans fail to operate with total loss of power.

The event rate of a diesel either failing to start is 3×10^{-2} per demand, or failing while running is 3×10^{-3} per hour (see Equipment Failure Rate Estimates). The diesels are not needed unless offsite power is first lost, which is event rate of 1×10^{-4} per hour. Thus, the probability in the same hour for loss of all electric power to fans is 3×10^{-6} assuming that the diesel fails on demand to start, which is the more frequent diesel event.

The helium pressure-boundary failure event rate is highest for the Refrigerator or Compressor Buildings and is 3×10^{-5} per hour [1]. Assuming loss of off-site electric power, diesel failure, and a pressure-boundary failure in the same hour yields a probability of 9×10^{-11} [1].

The Fatality Rate (Φ) is found to be:

$$\Phi = PF = (9 \times 10^{-11} \text{ in one hour})(1) = 9 \times 10^{-11} \text{ per hour}$$

Since the Fatality Rate is $<10^{-7}$ per hour, the ODH Class is Class 0.

Issue 3:
What is the ODH Class for the RHIC Refrigerator Building, in which the ASE allows only one of two fans to be operable, if 1) the operable ODH fan does not operate, and 2) a helium pressure-boundary failure occurs?

As described above, the Fatality Factor (F) will be 1 because the fans fail to operate. The probability of a fan failure in the Refrigerator Building occurring in the same hour as the helium pressure-boundary failure must be determined. The event rate of a fan either failing to start is 3×10^{-4} per demand, or failing while running is 1×10^{-5} per hour (see Equipment Failure Rate Estimates).

Examination of the above information shows that the most frequent scenario is the failure of a fan to start upon demand (3×10^{-4} per demand).

The helium pressure-boundary failure event rate for the Refrigerator Building is 3×10^{-5} per hour [1]. Thus, the probability of loss of the operable ODH fan, which stops all forced ventilation, occurring in the same hour as the pressure-boundary failure is 9×10^{-9}[1].

The Fatality Rate (Φ) is found to be:

$$\Phi = PF = (9 \times 10^{-9} \text{ in one hour})(1) = 9 \times 10^{-9} \text{ per hour}$$

Since the Fatality Rate is $<10^{-7}$ per hour, the ODH Class is Class 0.

Conclusions

The following conclusions are made:

(1) The diesels are not safety significant equipment because their operability is not necessary to maintain the ODH Class of any RHIC building.

(2) The subsequent failure of available fan(s) concurrent with the helium pressure boundary failure will not cause the ODH Class of any building to increase.

<u>References</u>

1. Karol, R., "Collider Building ODH Calculations – Revisited", April 18, 2000 (Revised 5/26/00).
2. Azarm, A., et. al., Level 1 Internal Events PRA for the High Flux Beam Reactor, Volume 1: Summary and Results (Rev. 1)", July 1990.
3. BNL Standards Based Management System, <u>Oxygen Deficiency Hazards</u>.